TEST RECORD NO. 2

Only the following tests were considered necessary for the DPC Controller for compliance to requirements for “Utility Interactive Inverters” per The Standard For Inverters, Converters and Controllers For Use In Independent Power Systems, UL 1741. Other tests were conducted in conjunction with Capstone Turbine Corp.’s Model 330 Stationary Engine Generator Assembly. See File AU2687, report dated April 2, 1999, and File AU2687(SP), Report dated April 4, 1999.

OUTPUT RATINGS/DC INJECTION TESTS:

METHOD

A sample of Model 30KW was connected to a source of supply capable of delivering twice the rated input current. The outputs were connected to its rated simulated utility supply, and the variable resistors were adjusted to result in the rated output voltage-amperes indicated.

During the test, the DC current injected into the utility was also measured.

RESULTS

				Output, ac			Measured Output, ac		
	Sample	Input		Phase-to-			Rated		Power
Model	No.	V	A	Phase, V	Total W	Pf	V	KW	Factor
30KW	1	-	-	485	29.2 kW	.9	480	30	1.000
				480	30.0 kW	1	480	30	1.0000

The measured DC input current was 220 mA and was less than 5 percent of the rated inverter output current.

ANTI-ISLANDING TEST:

METHOD - PART A (Anti-Islanding Test per UL 1471 [IEEE P929])

While the inverter was connected to a simulated utility providing output power at nominal voltage and frequency at the point of common coupling (specified below), a parallel RLC resonant circuit was placed between the inverter and simulated utility. The quality factor of the resonant circuit was determined to be 2.5 ± 3 percent (with the exception of operation at 125 percent) and the real load power was to be adjusted to place the inverter at 25%, 50%, 100% and 125% of the inverter's rated output.

The reactive load (either capacitive or inductive) was then adjusted to between 95% and 105% of the balanced condition in 1% steps. At each step, the inverter's trip time was measured on disconnect from the simulated utility.

RESULTS - PART A

Model:	330
Sample No.:	1
Rated Output:	480 V ac, 30 kW

1) 100% Output Power Condition

Real Power:	29.3 W
VAR_C	73.20 VA
VAR_L	73.01 VA (Balanced load condition)

$$Q = \sqrt{\frac{VAR_C \times VAR_L}{P_{REAL}}} = 2.49$$

Simulated Utility Conditions at Point of Common Coupling:

V_{PCC} = 275 V ac (L - N), $Freq_{pcc}$ = 59.999 Hz

RESULTS (Cont'd.)

Anti-Islanding Test 100%

	% of Balanced Load	**Actual Measured**	**Trip Time, mS**
1.	0.95 VAR_L = 69.54	VAR_L = 69.58	50
2.	0.96 VAR_L = 70.27	VAR_L = 70.30	51
3.	0.97 VAR_L = 71.00	VAR_L = 71.02	51
4.	0.98 VAR_L = 71.74	VAR_L = 71.77	49
5.	0.99 VAR_L = 72.47	VAR_L = 72.45	49
6.	1.00 VAR_L = 73.20	VAR_L = 73.20	50
7.	1.01 VAR_L = 73.93	VAR_L = 73.90	50
8.	1.02 VAR_L = 74.66	VAR_L = 74.70	50
9.	1.03 VAR_L = 75.40	VAR_L = 75.47	50
10.	1.04 VAR_L = 76.13	VAR_L = 76.14	51
11.	1.05 VAR_L = 76.86	VAR_L = 76.88	52

RESULTS (Cont'd.)

2) 125% Output Power Condition

Real Power: 37.1 W
VAR_C 91.02 VA
VAR_L 91.2 VA (Balanced load condition)

$$Q = \sqrt{\frac{VAR_C \times VAR_L}{P_{REAL}}} = 2.45$$

Simulated Utility Conditions at Point of Common Coupling:

V_{PCC} = 272 V ac (L - N), $Freq_{pcc}$ = 60 Hz

Anti-Islanding Test 125%

	% of Balanced Load	**Actual Measured**	**Trip Time, mS**
1.	0.95 VAR_L = 86.64	VAR_L = 86.70	70
2.	0.96 VAR_L = 87.55	VAR_L = 87.60	70
3.	0.97 VAR_L = 88.46	VAR_L = 88.50	75
4.	0.98 VAR_L = 89.37	VAR_L = 89.30	75
5.	0.99 VAR_L = 90.28	VAR_L = 90.20	70
6.	1.00 VAR_L = 91.20	VAR_L = 91.20	52
7.	1.01 VAR_L = 92.11	VAR_L = 92.20	70
8.	1.02 VAR_L = 93.02	VAR_L = 93.00	70
9.	1.03 VAR_L = 93.93	VAR_L = 94.00	70
10.	1.04 VAR_L = 94.84	VAR_L = 94.90	70
11.	1.05 VAR_L = 95.76	VAR_L = 95.70	70

RESULTS (Cont'd.)

3) 50% Output Power Condition

Real Power: 14.52 W
VAR_C 34.13 VA
VAR_L 34.70 VA (Balanced load condition)

$$Q = \sqrt{\frac{VAR_C \times VAR_L}{P_{REAL}}} = 2.37$$

Simulated Utility Conditions at Point of Common Coupling:

V_{PCC} = 276 V ac (L - N), $Freq_{pcc}$ = 59.999 Hz

Anti-Islanding Test 50%

	% of Balanced Load	**Actual Measured**	**Trip Time, mS**
1.	0.95 VAR_L = 32.96	VAR_L = 32.92	53
2.	0.96 VAR_L = 33.31	VAR_L = 33.10	50
3.	0.97 VAR_L = 33.65	VAR_L = 33.02	50
4.	0.98 VAR_L = 34.00	VAR_L = 34.03	50
5.	0.99 VAR_L = 34.35	VAR_L = 34.44	50
6.	1.00 VAR_L = 34.70	VAR_L = 34.70	52
7.	1.01 VAR_L = 35.04	VAR_L= 35.05	50
8.	1.02 VAR_L = 35.39	VAR_L = 35.35	52
9.	1.03 VAR_L = 35.74	VAR_L = 35.84	52
10.	1.04 VAR_L = 36.10	VAR_L = 36.17	52
11.	1.05 VAR_L = 36.43	VAR_L = 36.41	49

RESULTS (Cont'd.)

4) 25% Output Power Condition

Real Power: 7.83 W
VAR_C 17.2 VA
VAR_L 17.2 VA (Balanced load condition)

$$Q = \frac{\sqrt{VAR_C \times VAR_L}}{P_{REAL}} = 2.19$$

Simulated Utility Conditions at Point of Common Coupling:

V_{PCC} = 277 V ac (L - N), $Freq_{pcc}$ = 59.99 Hz

Anti-Islanding Test 25%

	% of Balanced Load	**Actual Measured**	**Trip Time, mS**
1.	0.95 VAR_L = 16.34	VAR_L = 16.32	50
2.	0.96 VAR_L = 16.51	VAR_L = 16.48	50
3.	0.97 VAR_L = 16.68	VAR_L = 16.67	52
4.	0.98 VAR_L = 16.85	VAR_L = 16.88	52
5.	0.99 VAR_L = 17.02	VAR_L = 17.01	52
6.	1.00 VAR_L = 17.20	VAR_L = 17.20	50
7.	1.01 VAR_L = 17.37	VAR_L = 17.36	50
8.	1.02 VAR_L = 17.54	VAR_L = 17.55	50
9.	1.03 VAR_L = 17.72	VAR_L = 17.74	48
10.	1.04 VAR_L = 17.88	VAR_L = 17.87	50
11.	1.05 VAR_L = 18.06	VAR_L = 18.07	50

The inverter did not island as a result of conducting testing at 25, 50, 100, and 125 percent power output, while the inverter was connected to a resonant RLC circuit.

Note: Unit was verified to have a 5-minute delay during this test.

HARMONIC DISTORTION TEST:

METHOD

Samples of the power inverters indicated were subjected to this test. The power inverter was connected to the input source of supply. The output was connected to a simulated utility with an impedance of 2 percent of the inverter impedance (through a specified delta to wye transformer on the output of the inverter where specified in the installation instruction instructions).

The total harmonic current distortion and the maximum single harmonic current distortion were measured.

RESULTS

Model	Sample No.	Percent of Phase Output	Phase	Output A	Output V	Total Current Harmonic Distortion	Maximum Single Harmonic
330	1	See Below	A	34.2	278	2.92	30 Kw
330	1	See Below	B	34.1	278	3.00	30 Kw
330	1	See. Below	C	34.5	278	2.99	30 Kw

ODD HARMONICS
Number

	Phase A	Phase B	Phase C
Total THD	1.937%	2.11%	2.18%

		A	B	C
1 - 9	1	0.661	.75	.78
11 - 15	1	.580	.76	1.0
17 - 21	1	.27	.48	.312
23 - 33	1	.25	.33	.27
> 33	1	.18	.18	.27

EVEN HARMONICS
Number

		A	B	C
2 - 10	1	.83	.70	.63
12 - 16	1	.42	.30	.39
18 - 22	1	.24	.16	.29
24 - 34	1	.13	.14	.13
> 36	1	.06	.07	.06

The maximum total harmonic distortion was less than 5 percent of the fundamental at "full" load. The odd harmonics did not exceed the distortion limits. The even harmonics did not exceed the allowable distortion limits.

UTILITY VOLTAGE AND FREQUENCY VARIATION TEST:

METHOD

While the inverter was connected to a simulated utility providing output power at nominal voltage and frequency at the point of common coupling (specified below), waveforms as described below were initiated from the simulated utility. The inverter's response to the waveform was recorded and the results were repeated for a total of ten times. A timer was used to determine the time at which the inverter resumed operation following the point of common coupling resuming nominal voltage and frequency. For three-phase inverters, the waveforms were applied to all three of the phases.

Note that each condition was repeated at:

FAST UNDERVOLTAGE TEST

Waveform 1 (Condition A) - The inverter was operated within normal utility operating parameters 480 Vrms, Wye, 60 Hz, and the simulated utility voltage was reduced to 331 V ac to determine the trip limit. The inverter needed to cease to export power within 0.1 seconds (6 cycles) of crossing the voltage trip limit. This test was repeated ten (10) times.

UNDERVOLTAGE TEST

Waveform 2 (Condition B) - The inverter was operated within normal utility operating parameters 480 Vrms, Wye, 60 Hz, and the simulated utility voltage was reduced to 417 V ac in 1 cycle and held for 2 seconds. The voltage was then restored to 480 V ac. The inverter needed to cease to export power within 2.0 seconds (120 cycles) of crossing the voltage trip limit. This test was repeated ten times.

OVERVOLTAGE TEST

Waveform 3 (Condition C) - The inverter was operated within normal utility operating parameters 480 Vrms, Wye, 60 Hz, and the simulated utility voltage increased to 532 V ac in 1 cycle and held for 2 seconds. The voltage was then restored to 480 V ac. The inverter needed to cease to export power within 2.0 seconds (120 cycles) of crossing the voltage trip limit. This test was repeated ten times.

FASTOVERVOLTAGE TEST

Waveform 4 (Condition D) - The inverter was operated within normal utility operating parameters 480 Vrms, Wye, 60 Hz and the simulated utility voltage was increased to 540 V ac in 1 cycle and held for 2 seconds in this condition before reducing the voltage to 480 V ac. The inverter needed to cease to export power within 2 cycles of crossing the voltage trip limit. This test was repeated ten times.

OVERFREQUENCY TEST

Waveform 5 (Condition E) - The inverter was operated within normal utility operating parameters 480 Vrms, Wye, 60 Hz, and the simulated utility frequency was increased from 60 Hz to the initial value shown under results with a ramp time of 2 seconds, then the frequency was ramped from the initial valueto a final value in one cycle. The inverter needed to cease to export power within 0.1 second six cycles of crossing the frequency trip limit. This test was repeated ten times.

UNDERFREQUENCY TEST

Waveform 6 (Condition F) - The inverter was operated within normal utility operating parameters 480 Vrms, Wye, 60 Hz and the simulated utility frequency was decreased from 60 Hz to the initial value shown under results with a ramp time of 2 seconds, then the frequency was decrease from the initial value to a final value in 1 cycle. The inverter needed to cease to export power within 0.1 seconds 6 cycles of crossing the frequency trip limit. This test was repeated ten times.

RESULTS

Simulated Utility Conditions at Point of Common Coupling

V_{PCC}: 480 V ac
Inverter-Rated Output: 30 kW
Inverter Output for Test: 2 kW

Waveform 1 - FAST UNDERVOLTAGE TEST

	Time (or Cycles) to Disconnect	Phase		Reconnection Time
1.	96.9 ms	59.92 ms (2 kW)	A	≥ 5 Minutes
2.	100.5 ms	59.92 ms (2 kW)	A	≥ 5 Minutes
3.	101.8 ms	54.92 ms (2 kW)	A	≥ 5 Minutes
4.	104.7 ms	53.32 ms (2 kW)	B	≥ 5 Minutes
5.	105.6 ms	54.72 ms (2 kW)	B	≥ 5 Minutes
6.	103.2 ms	48.72 ms (2 kW)	B	≥ 5 Minutes
7.	102.4 ms	54.52 ms (2 kW)	C	≥ 5 Minutes
8.	101.4 ms	48.02 ms (2 kW)	C	≥ 5 Minutes
9.	101.1 ms	47.82 ms (2 kW)	C	≥ 5 Minutes
10.	100.8 ms	58.92 ms (2 kW)	A	≥ 5 Minutes

Waveform 2 - UNDERVOLTAGE TEST

	Time (or Cycles) All Three Phases	Phase		Reconnection Time
1.	17.2 ms (1 cycle)	71.05 ms	C	> 5 Minutes
2.	17.3 ms	61.65 ms	C	> 5 Minutes
3.	15.7 ms	67.65 ms	C	> 5 Minutes
4.	15.0 ms	70.35 ms	A	> 5 Minutes
5.	17.5 ms	78.35 ms	A	> 5 Minutes
6.	17.6 ms	70.35 ms	A	> 5 Minutes
7.	17.3 ms	60.85 ms	B	> 5 Minutes
8.	16.3 ms	71.65 ms	B	> 5 Minutes
9.	17.2 ms	71.35 ms	B	> 5 Minutes
10.	17.2 ms	70.75 ms	B	> 5 Minutes

Waveform 3 - OVERVOLTAGE TEST

	Time (or Cycles) All Three Phases	Phase		Reconnection Time
1.	98.15 ms	160.2 ms	C	> 5 Minutes
2.	99.50 ms	242.2 ms	C	> 5 Minutes
3.	98.50 ms	192.7 ms	C	> 5 Minutes
4.	101.00 ms	192.2 ms	A	> 5 Minutes
5.	171.00 ms	193.2 ms	A	> 5 Minutes
6.	102.75 ms	202.2 ms	A	> 5 Minutes
7.	100.70 ms	192.2 ms	B	> 5 Minutes
8.	185.75 ms	184.2 ms	B	> 5 Minutes
9.	75.00 ms	159.2 ms	B	> 5 Minutes
10.	90.75 ms	193.2 ms	B	> 5 Minutes

Waveform 4 - FAST OVERVOLTAGE

	Time (or Cycles) to Disconnect Per Phase	Phase#		Reconnection Time
1.	22.32 ms		C	> 5 Minutes
2.	20.32 ms		C	> 5 Minutes
3.	19.22 ms		C	> 5 Minutes
4.	14.32 ms		C	> 5 Minutes
5.	18.82 ms		B	> 5 Minutes
6.	21.02 ms		B	> 5 Minutes
7.	18.32 ms		B	> 5 Minutes
8.	16.32 ms		A	> 5 Minutes
9.	21.32 ms		A	> 5 Minutes
10.	20.32 ms		A	> 5 Minutes

- Test conducted only on each individual phase.

RESULTS (Cont'd.)

Waveform 5 - Over Frequency

	Time (or Cycles) Output Power	Trip Frequency	Disconnect Time/Cycles
1.	2 kW	60-50 - 60.6	33.35 ms
2.	2 kW	60.60 - 60.7	39.35 ms
3.	2 kW	60.70 - 60.8	26.35 ms
4.	2 kW	60.83 - 60.9	33.75 ms
5.	2 kW	60.93 - 61.0	57.75 ms
6.	2 kW	61.00 - 61.1	34.75 ms
7.	2 kW	61.13 - 61.2	38.15 ms
8.	2 kW	61.20 - 61.3	27.15 ms
9.	2 kW	61.33 - 61.4	25.65 ms
10.	2 kW	61.43 - 61.5	51.55 ms

Waveform 6 - Under Frequency

	Time (or Cycles) Output Power	Trip Frequency Range	Disconnect Time/Cycles
1.	2 kW	59.47 - 59.4	69.63 ms
2.	2 kW	59.37 - 59.3	70.55 ms
3.	2 kW	59.27 - 59.2	47.75 ms
4.	2 kW	59.17 - 59.0	66.63 ms
5.	2 kW	59.07 - 59.0	45.75 ms
6.	2 kW	58.97 - 59.9	88.05 ms
7.	2 kW	58.67 - 58.6	66.63 ms
8.	2 kW	58.77 - 58.7	51.55 ms
9.	2 kW	58.57 - 58.7	66.63 ms
10.	2 kW	58.47 - 58.4	47.55 ms

Note: The above tests were performed varying the trip set points on the unit to different values.

ABNORMAL TESTS:

GENERAL

Unless otherwise stated, conditions described below were applied during each of the abnormal tests described on the following pages.

A. Units provided with bottom openings were placed on a softwood surface covered with white tissue paper, and a single layer of cheesecloth was draped loosely over all ventilation openings. The cheesecloth was untreated cotton cloth running 14-15 yd/lb (28-30 m^2/kg) and having, for any square inch, a count of 32 threads in one direction and 28 threads in the other direction.

B. For units having supporting feet made of rubber or neoprene material, the feet were removed, unless the physical properties of the material were investigated.

C. The dead-metal parts of the enclosure were connected directly to ground.

D. Each test was conducted, until further change as a result of the test was not likely. If an automatic reset protector functioned, the test was continued for 7 hours. If a manual reset protector functioned, the test was continued for 10 cycles, except for a Listed molded-case circuit breaker which was continued for 3 cycles. The cycling rate for manual reset protectors was the minimum resetting time but not faster than 10 cycles/4 minutes.

E. The test was terminated, if any of the following conditions occurred:

   1. One or more components such as capacitors, diodes, resistors, solid-state devices, or the like opened or shorted,

   2. The intended branch circuit over-current protective device functioned, or

   3. An internal fuse or thermal cutoff opened.

F. Unless otherwise indicated, immediately following completion of each abnormal test a dielectric potential of twice-rated voltage plus 1000 V was applied as follows for a period of 1 minute during each test:

   1. 1960 V ac, 60 Hz between DC input and AC output circuit and dead-metal parts.

OUTPUT SHORT-CIRCUIT ABNORMAL TEST:

METHOD

Samples of the power inverters indicated below were subjected to this test. The input circuits were connected to a simulated source of supply. The output circuits were connected to output leads 4 ft in total length which resulted in a short-circuit condition.

The source of supply was fused in accordance to manufacturer’s installation instructions.

The test was:

A. Continued for 7 hours, since an automatic reset protector was provided in the secondary output circuit (i.e. no additional protection was provided.)

B. Continued for 50 cycles of operation, since a manual reset protector was employed in the secondary output circuit.

C. Continued until the external protection (i.e. time delay fuse) opened. The test was conducted three (3) separate times.

The test was repeated four (4) times so the short occurred in different portions of the line cycle.

Output Line Voltage: 480 V
Inverter Loaded to: 30 W
Maximum Inverter Output Current: 46.35 A

RESULTS

Model	Sample No.	Test Condition for Inverter L-L/L-N	Did External 3 A Ground Fuse in Input Circuit Open?	Remarks	Side of Output Transformer
330	1	L-L	No	No hazard. Unit shut down.	W/A

There was no emission of flame or molten metal.

Test Record Summary:

The results of this investigation indicate that the samples evaluated comply with the applicable requirements, and therefore, such products are judged eligible to bear UL’s Mark as described on the Conclusion Page of this Report.

Test Record by:	Reviewed by:
Adalberto Margarito/aal	**Robert Gill/aal**
ADALBERTO MARGARITO	ROBERT GILL
Project Engineer	Engineering Group Leader
Conformity Assessment Services	Conformity Assessment Services